PLATINUM–GROUP METALS

By Henry E. Hilliard

Domestic survey data and tables were prepared by Mahbood Mahdavi, statistical assistant, and the world production table was prepared by Regina R. Coleman, international data coordinator.

In 2002, the Stillwater Mining Company, Columbus, MT, was the only domestic producer of primary platinum-group metals (PGM). Stillwater operated the Stillwater Mine, near Nye, MT, and the East Boulder Mine, south of Big Timber, MT, and produced 19,200 kg of PGM.

Domestic supply of platinum, which includes mine production, production from scrap, and stocks of platinum, grew by about 10%, due largely to increased output by the Stillwater's East Boulder Mine. During the same period, domestic palladium supply increased by about 17%, owing to increased production at the East Boulder Mine and the buildup of palladium stocks, primarily by automobile manufacturers.

Global consumption of palladium decreased sharply in 2002 as consumers switched to alternative materials, engaged in thrifting, and used stocks accumulated prior to 2002. Johnson Matthey plc estimates that consumption of palladium for auto catalysts in 2002 exceeded purchases (demand) by 46,700 kg as U.S. and other auto manufacturers made large-scale use of inventory stocks. Globally, supplies of palladium decreased as Russia restricted sales. The market, however, remained in surplus and the price of palladium dropped to a low of $220 per ounce.

In 2002, the automobile industry continued to be the major consumer of PGM. Auto catalysts accounted for approximately 98% of rhodium demand, 66% of palladium demand, and 41% of platinum demand. Despite strong vehicle sales in 2002, demand for palladium declined, as automakers and electronic component makers made concerted efforts to reduce the palladium content of their products. Nevertheless, palladium remains crucial to the control of exhaust emissions; it has proven advantages in the control of hydrocarbons and its quicker startup makes it particularly suitable for use as a manifold catalyst.

According to Johnson Matthey plc, purchases of rhodium by the automobile industry for use in catalytic converters decreased by 7,400 kg to 17,900 kg in 2001 and by about 200 kg to 17,700 kg in 2002. In 2002, rhodium supplies were unchanged from the 2001 level as South Africa increased production while Russian output decreased.

Demand for ruthenium, used primarily in ruthenium-based catalysts and in the manufacture of resistors for the electronics industry, increased slightly in 2002 as consumers in the electronics industry exhaust large inventories built up in 2000-01. Iridium demand, however, fell by about 6% as the oversupply of iridium crucibles persists in the electronics industry. Iridium's primary use in the electronics industry is in the form of crucibles used to grow high-purity crystals. Overcapacity has persisted in this sector following strong demand in 2000-01.

Legislation and Government Programs

On May 1, 2002, the U.S. Department of Defense's Defense Logistics Agency (DLA) increased its FY 2002 sales limit for platinum to 4,361 kg from a planned 2,959 kg and its iridium sales to 187 kg from a planned zero kg. On October 1, 2002, DLA announced that its FY 2003 Annual Materials Plan (AMP) was in effect. The plan proposed the sale of 10,900 kg of palladium, 1,560 kg of platinum, and 187 kg of iridium. Actual sale quantities were limited to remaining disposal authority or inventory. The FY 2003 AMP expired on September 30, 2003.

The Fiscal Year 2003 iridium sales program began on January 27, 2003. Under the Basic Ordering Agreement (BOA), prospective customers were required to preregister to participate in the iridium sales and be considered for subsequent contract awards. Before customers are qualified to engage in the quoting process, they must submit a completed BOA agreement package to the iridium contract specialist, who evaluates the agreement package and renders a decision in writing. The iridium listed for sale is in the form of $99.95% sponge, <99.9% sponge, and <99.9% powder. The material was acquired from several suppliers/producers during 1951-92. The quality of the material is taken from certificates of analysis from Government contract laboratories or original certificates from the suppliers/producers; if no certificate is available, the appropriate DNSC Purchase Specification is used (Defense Logistics Agency, 2003, p. 1; Donna Black, contract specialist, Defense Logistics Agency, written commun., January 6, 2003).

Production

The Stillwater Mining Co. operates the Stillwater Mine in Nye, MT, and in 2002 reported the production of 19,200 kg of palladium and platinum, more than 17% higher than the 16,380 kg produced in 2001. Of the 19,200 kg produced, palladium accounted for 14,800 kg, and platinum accounted for 4,390 kg. Mine production was defined by Stillwater as the quantity of PGM contained in a concentrate at the time it was shipped to the smelter. The company milled 1.14 million metric tons (Mt) of ore in 2002, 36% more than in 2001. The mill head grade was 16.8 grams per metric ton (g/t) of combined palladium and platinum, compared with 19.6 g/t in 2001.

Stillwater revised its operating plans for the 4th quarter of 2001 by pausing its expansion plan at the Stillwater Mine and completing

construction at its East Boulder Mine for operations at 50% of the mine's ultimate 1,820 metric tons (t) per day of ore design rate. The change in plans followed the palladium price collapse that took place shortly after the terrorist attacks on September 11, 2001. The fall in price sharply reduced cash flow from operations that were an important source of financing for the company's expansion programs. Under the revised operating plan, combined PGM production for the Stillwater and East Boulder Mines was projected to be 23,000 kg in 2002 and 22,700 kg in 2003 and 2004. Production under the original expansion plan was expected to reach 31,100 kg in 2003 (Stillwater Mining Company, 2003, p. 10).

Stillwater also operated a smelter and base-metal refinery at its metallurgical complex in Columbus, MT. Expansion of the smelter has continued since it was commissioned in 1999. A concentrate sampling and drying facility for production from both mines was commissioned in May 2001. A second top-blown rotary converter was commissioned in November 2001 and other ancillary equipment to support the simultaneous operation of two converters was in place in the first quarter of 2002. In 2002, the company's refinery shipped 21,118 kg of PGM including 15,854 kg of palladium and 5,264 kg of platinum. In addition, the refinery shipped as byproducts, 268 kg of rhodium, 364 kg of gold, 1,358 kg of silver, 345 t of copper, and 639 t of nickel in solutions and crystals. During 2002, byproduct sales of copper and nickel were equivalent to 1.4% of the company's revenues.

Stillwater's automobile catalyst recycling effort also continued to grow in 2002. During 2002, the smelter processed 940 t of spent autocatalysts, recovering 1,440 kg of palladium and platinum, 33% less than the 2,143 kg recovered in 2001. Spent autocatalysts typically contain two parts platinum to one part palladium, reflecting the metals use in older clean-air technology. This ratio will shift in time as the palladium-dominant catalysts used in 1999-2001 begin to be recycled.

Stillwater's proven and probable reserves are contained in the J-M Reef, a 45-kilometer-long ore body in the Beartooth Mountain Range in south-central Montana. The average ratio of palladium to platinum contained in the reef is 3.5 to 1. The company's proven and probable ore reserves as of December 31, 2002, totaled 18 Mt with an average grade of 18.7 g/t, containing 787,000 kg of palladium and platinum (Stillwater Mining Company, 2003, p. 5-9).

Secondary production of PGM from spent autocatalysts and other PGM-bearing waste materials yielded increased amounts of metal in 2002 when compared with that of 2001. Palladium and platinum contained in catalytic converters from end-of-life vehicles helped push the amount of PGM recovered from this source to 23,000 kg in 2002 versus 20,000 kg in 2001. Increasingly stringent regulations designed to reduce hydrocarbons and nitrogen oxides emissions prompted higher loadings of palladium in autocatalysts beginning in 2000. Increased demand and short supplies prompted sharply higher prices and an attendant increase in the secondary recovery of palladium. About 11,000 kg were recovered in the United States in 2002, up from more than 8,000 kg in 2001. Johnson Matthey reported that global recovery of rhodium from spent autocatalysts reached 3,100 in 2002, up 11% from 2,800 kg in 2001. The United States accounted for most of the increase, although significant increases were reported for Europe and Japan (Johnson Matthey plc, 2003, p. 23-28).

Consumption

In 2002, platinum sales increased by 5% to about 204,000 kg, driven by strong demand by the Chinese jewelry market and by increased use of platinum in catalytic converters. Increased sales of diesel cars, rising light vehicle output, tighter emissions regulations, and greater use of platinum based catalysts at the expense of palladium combined to increase the consumption of platinum in auto catalysts by about 17%. However, purchases of platinum by auto manufacturers increased by less than 4% as some satisfied a major portion of their platinum needs from stocks.

Purchases of palladium by the auto industry declined sharply in 2002 owing to the substantial use of stocks. Consumption of palladium also declined as a result of thrifting programs and increased use of platinum-based catalysts (Johnson Matthey plc, 2003, p. 3-8).

U.S. apparent consumption of platinum was estimated at about 80,000 kg. U.S. industry consumed an additional 12,000 kg of platinum recovered from spent auto catalysts. U.S. apparent consumption of palladium in 2002 was estimated at 61,000 kg.

Platinum.—Despite continued growth in consuming sectors, U.S. demand for platinum decreased by about 40% in 2002 to about 15,000 kg as automakers used their platinum stocks to supplement purchases of the metal. Programs initiated in 2000 and 2001, when the price of palladium was at its highest, resulted in increased platinum consumption in 2002 by platinum's major consuming sectors.

Diesel powered vehicles have become increasingly popular in Europe and are expected to account for more than 30% of the market in 2002. At the same time, platinum loadings for diesel engines have been increased in order to comply with European Stage III emissions requirements, which apply to all new vehicles manufactured after 2001 (platinum-loaded autocatalysts are more efficient than palladium-loaded catalysts for reducing emissions from diesel engines). The use of platinum in diesel catalysts is expected to account for almost three-quarters of demand from the European automotive sector. The increased use of platinum in gasoline vehicles was somewhat offset by decreased demand in the electronics, glass, and jewelry industries.

Global demand for platinum in jewelry recovered from its 4-year low in 2001 of 79,300 kg to about 87,000 kg in 2002. There was a 23% decline in consumption by the jewelry trade in the United States as sales fell back in response to the weaker U.S. economy. Higher platinum prices in 2001 and 2002 were the main cause of the decline, which caused a loss of market share to white gold in the lower-price segments of the market and encouraged the recycling of old stocks of platinum jewelry (Johnson Matthey plc, 2003, p. 24).

Palladium.—High prices in 2000-01 continued to have a negative impact on U.S. demand for palladium, which declined by more than 60% to about 30,000 kg. High prices had the greatest impact on the automotive sector where manufacturers reduced their

purchases of the metal through substitution, thrifting, and working off large inventories. The electronics industry was also hit by high palladium prices; however, producers of multilayer ceramic capacitors were successful in replacing palladium with lower-priced nickel and silver in all but the highest-performance capacitors. Purchases of palladium increased in 2002 as palladium metal and manufactured components accumulated in 2001 were depleted (Johnson Matthey plc, 2002, p. 15-16).

Prices

While the price of palladium sank to near record lows in 2002, the price of platinum continued to climb, averaging $542.56 per ounce in 2002 compared with $533.29 in 2001. Market conditions carried the price of platinum to an 18-month high of $605 per troy ounce (ounce) in mid-November, subsequently falling back and stabilizing at around $590 in the first quarter of 2003.

The palladium price set a record in 2000, ending the year at an average of $691.84 per ounce. Fueled by anxiety over delays in Russian exports and heightened speculative interest, the price continued to rise into January and February 2001. The spot palladium price rose to $1,075 per ounce at the London PM Fix on February 5, 2001, and nearby future contracts on NYMEX reached a record settlement of $1,082.80 per ounce (Platts Metals Week, 2001). The price began to fall on February 9, 2001 (falling $25 to $1,015 per ounce on the London PM Fix, and the March contract on NYMEX fell $31.90 to reach a settlement price of $1,010) and the decline continued through all of 2002. The opening price for the year ($440 per ounce) proved to be the 2002 high, and the price continued to decline into the first quarter of 2003.

Palladium.—The price of palladium began 2002 at almost $430 per ounce; as recently as April 2001 the price was more than $1,000 per ounce. The price slipped below $400 per ounce after the Ford Motor Company announced on January 11 that it would take a $4.1 billion charge against its 4th quarter 2001 results, which included a pre-tax charge of $952 million to cover the loss in value of precious metals, mostly palladium, the company purchased when the price of the metal was high (American Metal Market, 2002a). The price of palladium dipped further in April when Ford reported in a filing with the Securities and Exchange Commission that it had begun selling its stockpiles of the metal. Ford also reported that it would reduce its palladium requirements by more than 50% as a result of a breakthrough in catalyst formulations. As a result, in April the price fell back to trade in the $360 to $370 band (American Metal Market, 2002b).

More downward pressure was placed on the price of palladium in mid-May when Johnson Matthey released its annual report on PGM, reporting deteriorating demand, with the dominant autocatalyst sector down 11% and electronics slumping by more than 60%. The price increased somewhat during the week of May 20 due to strong Japanese buying, but fell back to nearly $450 by the end of the month. The prices fell to below $320 in June and traded in the narrow range of $316 to $330 per ounce in July. Reports that Russian selling palladium metal surfaced at the end of July, caused the price to fall to the $310 to $315 range in the first week of August. The price moved briefly above $330 per ounce in the middle of September but quickly softened to below $320 by the end of the month. The price ebbed even lower in October, reaching $302 per ounce on October 24, its lowest since mid-1999. Palladium continued its slide in November, falling to $255 per ounce, following the release of the Johnson Matthey Interim Platinum 2002 report with its bearish prediction for demand in 2002. In December, the price of Palladium fell to below $250 per ounce, its lowest since November 1998.

Platinum.—Platinum traded in the range $470 to $490 per ounce during January 2002. The price fell to $454 per ounce on February 1, its low for the year, before recovering to $493 by the end of the month. The price broke above $500 per ounce on March 4 and reached $526 on March 11. The rise in price was driven by increased buying by speculators amid growing signs that the U.S. economy was recovering faster than expected and resurgent platinum jewelry sales in China, the United States, and the United Kingdom. In May, Johnson Matthey released its annual PGM report on the health of the platinum market, prompting platinum to rally once again to $550 per ounce. The price of platinum lost ground in August and part of September, plagued by concerns over the outlook for industrial demand in the wake of weak U.S. manufacturing figures. In October, platinum traded in the range $560 to $565 before starting to climb by mid-October when the price moved to about $600 per ounce. The price averaged $595 for the month of November, its highest since May 2001, and stabilized at the $590 level for the remainder of the year.

Trade

In 2002, U.S. net import reliance as a percentage of apparent consumption was estimated at 87% for palladium and 66% for platinum. South Africa accounted for 59% of refined platinum and 25% of refined palladium imports; Russia accounted for 28% of refined palladium imports and 4% of refined platinum imports. Total palladium imports decreased 27% to 116,600 kg from 160,000 kg in 2001; platinum imports increased 90% in 2002 to 160,500 kg from 84,150 kg in 2001. Rhodium imports were 8,630 kg, down from 12,400 kg in 2001. The United States exported 42,700 kg of palladium (36,800 kg in 2001), 27,800 kg of platinum (29,300 kg in 2001), and small amounts of other PGM.

World Review

In 2002, world mine production of PGM increased by about 4%, to 423,000 kg, compared with 408,000 kg in 2001 (table 5). South Africa, the world's leading producer of PGM, accounted for 57% of total mine production in 2002; Russia accounted for 31% and the United States 5%. Primary producing mines are also in Australia, Canada, and Zimbabwe. The remainder of mine production was produced by a number of other countries, mainly as a byproduct of copper and nickel operations. South Africa, which accounted for

73% of total mine production of platinum, increased its output by 3% in 2002 to 133,796 kg. This dominance in platinum production is likely to continue for some time as the country's Bushveld Igneous Complex is estimated to contain more than 75% of the world's platinum reserves. Russia dominated the world's mine production of palladium with 48% of total mine production; Russia's output of palladium was estimated to have decreased by 1% to about 84,000 kg in 2002.

Australia.—If all goes as planned, construction on Australia's first primary platinum producer—Platinum Australia Ltd.'s (PLA) Panton project—could begin in 2003 with production due to start in 2004. The decision to begin construction depends on the outcome of a bankable feasibility study that was due for completion in late 2002. Work on the study began in July 2001 after the favorable outcome of a prefeasibility study. The feasibility study was to have been completed in March 2001 but was extended to allow further work on a new metallurgical process.

The new metallurgical process involves the use of cyanide leaching to produce a high-grade concentrate. Cyanide leaching is used widely in the gold industry, and therefore carries a low technical risk. However, none of the world's PGM producers use this metallurgical procedure. Cyanide leaching has been tried before and shown not to be efficient on the more complex platinum ores. According to PLA, the new process has been proven in the laboratory and further research at pilot plant level was in progress.

PLA executives expect that the Panton mine will treat about 1 million tons per year of ore grading 5 grams per ton precious metals to produce 3,000 to 4,000 kilograms per year (kg/yr) of PGM and gold along with 1,000 to 1,500 tons per year (t/yr) nickel; 500 to 800 t/yr copper; and 50 to 100 t/yr cobalt (Australian Platinum Conference, 2002a).

Burundi.—When Argosy Minerals began exploring for lateritic nickel in the Musongati area of the African country of Burundi, it was seeking to increase its share of the global nickel market. Instead, it found what the company's manager of corporate development described as Africa's new platinum province. Argosy began its African exploration in 1998. However, the outbreak of intertribal hostilities in 2000 forced Argosy to put its exploration plans on hold. By April 2002, conditions had improved to the point that Argosy's technical personnel returned to Musongati and restarted work. Musongati offered Argosy the location and geologic setting for what could ultimately become a successful PGM project. The area reportedly has two distinct types of deposits. One consists of shallow continuous zones of PGM mineralization in an overlaying laterite profile. The second consists of disseminated sulfides hosting PGM in underlaying complex continuous zones to more than 400 meters (m) vertical depth. Another plus for development of the project is the extensive and good-quality geological data that had been collated by the Geological Survey of Burundi along with a substantial core library. The Musongati deposit is 26 kilometers (km) wide and 20 km long with the primary mineralization of cobalt and nickel that also contains PGM. The target resource estimate of 20 million t at 1.42 grams per ton palladium and platinum equates to 28,400 kg of contained palladium and platinum (Australian Platinum Conference, 2002b).

Russia.—Delayed shipments of palladium metal from Russia have disrupted the palladium market since 1998. Volatility and price spikes were prevalent during this period causing most of its consumers, looking for price stability and security in supplies, to substitute other PGM, precious metals, and base metals. The result has been that palladium lost market share in most of its end-use sectors.

Russia has the potential to increase its production of PGM by more than 40% in the next few years, according to a study led by the U.S. Geological Survey. The study was based on previously unavailable published Russian information on the PGM content of reserves at MMC Norilsk in East Siberia and Norilsk's development plans. Norilsk produces almost all of Russia's PGM, approximately 50% of the world's palladium, and 15% of the world's platinum (Bond and Levine, 2001).

Norilsk Nickel continued its moratorium on spot sales of palladium that began in 2001, but continued to sell under contracts. Also, Gokhran, the Russian state agency responsible for palladium stockpiles, reported that no sales were made from government stockpiles in 2002 in support of Norlisk's position. The net result was a more than 50% drop in sales of palladium from Russia.

On November 21, 2002, MMC Norilsk Nickel, Moscow, and Stillwater Mining Company, Colombus, MT, jointly announced the signing of agreements whereby Norilsk Nickel will acquire a 51% majority ownership in Stillwater through the issuance of 45.5 million newly issued shares of Stillwater common stock in exchange for $100 million cash and approximately 27,300 kg of palladium valued at $241 million based on the November 19, 2002, London PM Fix. Under the agreement, Norilsk will also commence a cash tender offer within 30 days of the closing to acquire additionally up to 10% of the currently outstanding shares of Stillwater at a price of $7.50 per share if the Stillwater share price is below $7.50 per share during the 15 trading days after closing. The additional share purchases would increase Norilsk Nickel's ownership in Stillwater to approximately 56% (Stillwater Mining Company, 2003, p. 3).

South Africa.—In 2002, South Africa produced about 239,761 kg of PGM, 5% more than the 228,700 kg produced in 2001. Producers initiated aggressive plans to increase production of PGM over the next 5 to 7 years—plans that are in line with the projected growth in demand. Anglovaal Mining and Impala Platinum formed a joint venture to develop a new mine at the Dwars River property. The property, south of the town of Steelpoort in South Africa's Mpumalanga Province, lies on the UG2 and Merensky reefs, which provide the country with much of its PGM reserves. The property is expected to produce 3,000 kg/yr of PGM over a period of 20 years (Impala Platinum Holdings Ltd., 2002).

In 2002, Aquarius Platinum Ltd. made its first significant venture outside South Africa by agreeing to buy a 50% interest in the Mimosa platinum mine in Zimbabwe. Mimosa is located on the Wedza Geological Complex on the southern portion of the Great Dyke, 125 km east of Bulawayo. Mimosa reportedly has proven and probable reserves totaling 70.5 Mt (of which 27% is proven) at an average grade of 1.84 g/t platinum, 1.55 g/t palladium, 0.15 g/t rhodium, and 0.38 g/t gold. Mimosa is a shallow underground mine, extending to a depth of about 300 meters (m). The mine, which started production in 1997, is currently producing at the rate of about 970 kg/yr PGM (470 kg platinum). An expansion is under way that will increase production to 4,200 kg/yr of PGM plus gold by April 2003 after which there is further potential for low-cost expansion to 7,700 kg of PGM plus gold (Mining, Journal, 2002a; Impala Platinum Holdings, Ltd., 2003).

Anglo American Platinum Corporation (Anglo Platinum), the world's leading platinum producer, made plans to increase its annual

platinum production to 112,000 kg by 2006. The expansion in output will be from a number of new mines as well as expansions and further mechanization of existing operations. A state-of-the-art smelter was under construction at Polokwane, with commissioning scheduled for the fourth quarter of 2002. A single hatch, six-in-line furnace of 68 megawatt operating power capable of smelting more than 600,000 t per year of concentrate was being installed. The furnace was designed to achieve the high operating temperatures necessary to smelt high chromite-bearing concentrates. The smelter, which will serve the Eastern Limb operations, is expected to account for 40% of Anglo Platinum's production (Mining Magazine, 2002).

Zimbabwe.—Mining investments in Zimbabwe have often been discouraged by the country's political and economic instability. In 2001, a new framework for investing in platinum mining was proposed and, if implemented, would relax foreign exchange restrictions, grant permission to create offshore bank accounts, and reduce the tax rate on platinum operations. An improved climate for investment will likely lead to funding for the development of the Ngezi opencast mine. Zimbabwe Platinum Mines Ltd. (Zimplats), which owns the mine, reported that it had carried out a 3-month trial mining program at Ngezi and full-scale mining would begin as soon as favorable mining legislation is implemented. The Ngezi platinum mine is expected to produce at least 2.2 Mt/yr of unrefined ore. A 2-Mt/yr mining rate is considered a minimum, and, if the project proceeds, the tonnage is expected to increase. The mine processing plant would include a conventional crusher, mill, concentrator, and dryer. Ore will be processed at the Selous Metallurgical Complex at the Hartley mine site, producing 6,500 kg of PGM contained in matte. This material will be transported to Impala Refining Services in South Africa for refining and marketing. Zimplats owned a 33.3% share in Australia-based Broken Hill Proprietary Company Limited before the company closed Hartley. Impala Platinum acquired a 30% stake in Zimplats' Ngezi project and the Hartley Platinum joint venture for R240 million (Metal Bulletin, 2001).

Current Research and Technology

Fuel Cells Could Replace Batteries.—Miniature fuel cells in a flat-pack configuration are being developed as alternatives to rechargeable batteries in cellular telephones, laptop computers and other small, portable electronic devices. The fuel cells exploit the catalytic (usually platinum-ruthenium catalysts) electrochemical oxidation of organic fuel (usually methanol) in air. Power sources based on state-of-the-art lithium-ion batteries have specific energies of no more than ≈ 150 watt•hour/kilogram (W•h/kg) and must be recharged before using. Power sources based on the present developmental fuel cells are expected to have specific energies between 500 and 1,000 W•h/kg and can be refueled and used immediately. A typical basic flat-pack fuel cell assembly contains a single polymer electrolyte membrane that serves as multiple cells. The cathodes of all the cells are located side by side in the same plane on one side of the membrane, while the anodes of all the cells are similarly located on the other side of the membrane. The preferred anode catalyst is platinum-ruthenium; the preferred cathode catalyst is platinum (Electronic Design, 2002).

Ruthenium-based Catalyst Mimics Photosynthesis.—Chemists at the University of Texas (Arlington) and the University of Messina (Italy) reported the development of a ruthenium-based catalyst that could lead to systems that mimic photosynthesis. Designing a system for photosynthesis that mimics plants' ability to absorb light and channel that energy into storage for chemical reactions has been a long-standing objective of chemical research. The most challenging part of the photosynthetic equation is the storage component, which requires a catalyst that can hold onto light-generated electrons and use them effectively for synthesis. An important parameter for the catalyst that determines the sophistication of its chemistry is the electron storage capacity. Although many of the photo catalysts being studied are capable of one- or two-electron processes, the University of Texas and the University of Messina researchers reported that upon visible-light irradiation, the ruthenium catalyst can reversibly store up to 4 electrons in localized orbitals. The catalyst is a ruthenium-phenanthroline dimer with a fully conjugated heteronuclear bridge (Today's Chemist, 2002).

Graphite Fuel Cell Electrodes.—Graphite may serve as effective support material for fuel-cell electrodes, according to researchers at Northeastern University, Boston, MA, and Villanova University, Villanova, PA. The high cost of platinum catalysts needed to oxidize fuels remains a key obstacle to widespread commercialization of fuel cells. Researchers are trying to find ways to reduce the dependence on platinum without sacrificing fuel cell performance. The researchers determined that in methanol oxidation studies, fuel-cell anodes made from graphite nanofibers with platelet and ribbon-type structures require a platinum loading of just 5 weight-percent to function as effectively as carbon electrodes loaded with 5 times more platinum. In addition, the graphite-nanofiber supported catalysts were found to be much more resistant than traditional catalysts to carbon monoxide poisoning (Journal of Physical Chemistry B, 2001).

Outlook

Lack of above-ground stocks and irregular shipments from Russia have influenced PGM price trends and caused volatility in the market since 1997. Most of South Africa's PGM, or about 57% of the world's supply (73% of the platinum), is sold by long-term contract to industrial consumers and never appears on the spot market. This leaves the marginal sales to Russia, which provides 20% to 30% of the market, but has essentially no long term contracts that could influence market prices in the margin. However, in October 2002, MMC Norilsk Nickel announced that its Norimet trading arm had signed a long-term palladium, platinum, and rhodium supply contract with General Motors Corp., effective from the end of 2002. Securing long-term supply contracts with large industrial consumers marks a step forward in Norilsk's strategy to secure long-term contracts with end users at the expense of spot sales, ensuring greater stability in its PGM deliveries and helping to steady PGM prices (Mining Journal, 2002b).

In 2002, several milestones in the development of light-duty hydrogen fueled vehicles were witnessed. Road tests demonstrated the

technology's reliability and viability, and all of the major automobile manufacturers announced that they would begin testing and demonstrating fuel cell vehicles in 2003. In 2002, one of the last major obstacles was, to a large extent, removed. Prior to 2002, many developers favored using fuels already available and existing infrastructures. However, most fuel cell vehicle developers have now adopted compressed hydrogen as the fuel of choice and construction of hydrogen fueling stations are now under way, especially in Japan. The International Platinum Association (IPA) estimates that about 50,000 fuel cell-powered automobiles per year could be produced by about 2012, with the vehicles becoming more widespread as technology improves in subsequent years. In discussions with Congressmen, Federal Regulators, and U.S. Geological Survey personnel, IPA pointed out the environmental benefits of PGM, including future PGM use in fuel cell technology. IPA estimates that each fuel cell-powered vehicle would use slightly more platinum than the current average catalytic converter-equipped passenger vehicle, but cautioned that the basic technology for fuel cells is not finalized. Other estimates have placed platinum requirements at 50 to 100 grams (g) for each fuel cell-powered vehicle, more than 10 times the current 3 to 5 g of PGM per vehicle equipped with a catalytic converter.

While platinum is the catalyst of choice for use in fuel cell technology, palladium also could potentially play a larger role that may significantly increase demand for the metal. The key to implementing automobile-based fuel cell technology is to establish an onboard hydrogen gas source. One option is to deploy a fuel processor upstream of the fuel cell that takes a liquid hydrocarbon and chemically processes it—most notably by catalytic steam reforming, into a hydrogen gas stream suitable for the fuel cell. In its hydride form, palladium has the capacity to absorb 800 to 900 times its own volume of hydrogen at room temperature and pressure that could serve as an onboard reservoir for hydrogen gas.

Other trends that could lead to increased demand for PGM are upcoming U.S. Government regulations on vehicle emissions, including the so-called Tier 2 restrictions scheduled to take effect in 2004, Tier 3 rules for off-road vehicles in 2006, and increased restrictions on diesel trucks and busses in 2002.

References Cited

American Metal Market, 2002a, Ford decision proves painful for palladium: American Metal Market, v. 110, no. 62-4, April 5, p. 1-2.
American Metal Market, 2002b, Ford's new catalytic converter will utilize rare earths: American Metal Market, v. 110, no. 64-1, April 15, p. 4.
Australian Platinum Conference, 2002a, Musongati—The new platinum province: Australian Platinum Conference, 2d, Perth, Western Australia, June 18-21, 2002.
Australian Platinum Conference, 2002b, Panton site visit: Australian Platinum Conference, 2d, Perth, Western Australia, June 18-21, 2002.
Bond, A.R. and Levine, R.L., 2001, Noril'sk Nickel and Russian platinum-group metals production: Post-Soviet Geography and Economics, v. 42, no. 2, p. 77-104.
Defense Logistics Agency, 2003, DLA-iridium-003, Basic ordering agreement for iridium: Defense Logistics Agency, January 6, 47 p.
Electronic Design, 2002, Small fuel cells get closer to replacing batteries: Electronic Design, v. 50, no. 11, May 27, p. 34.
Impala Platinum Holdings Ltd., 2002, Annual report 2001: Impala Platinum Holdings Ltd., p. 43.
Impala Platinum Holdings Ltd., 2003, Annual report 2002: Impala Platinum Holdings Ltd., p. 79.
Johnson Matthey plc, 2002, Platinum 2002: Johnson Matthey plc, May, 52 p.
Johnson Matthey plc, 2003, Platinum 2003: Johnson Matthey plc, May, 52 p.
Journal of Physical Chemistry B, 2001, Graphite nanofibers as an electrode for fuel cell applications: Journal of Physical Chemistry B, v. 105, no. 6, February 16, p. 1115-1118.
Metal Bulletin, 2001, Implats takes stake in Zimplats and Ngezi: Metal Bulletin, no. 8563, April 2, p. 10.
Mining Journal, 2002a, Aquarius buys into Mimosa: Mining Journal, v. 338, no. 8689, June 14, p. 432.
Mining Journal, 2002b, Platinum squeezed: Mining Journal, v. 339, no. 8706, October 11, p. 260.
Mining Magazine, 2002, Anglo Platinum's far reaching plans: Mining Magazine, v. 187, no. 2, August, p. 53.
Platts Metals Week, 2001, Palladium price hits record level, then plunges: Platts Metals Week, v. 72, no. 7, February 12, p. 14.
Stillwater Mining Company, 2003, 2002 annual report: Columbus, MT, Stillwater Mining Company, February 18, 91 p.
Today's Chemist, 2002, Storing, leaf-like: Today's Chemist, v. 11, no. 11, November, p. 10.

GENERAL SOURCES OF INFORMATION

U.S. GEOLOGICAL SURVEY PUBLICATIONS

Platinum-Group Metals. International Strategic Minerals Inventory Summary Report, Circular 930-E, 1986.
Platinum-Group Metals. Ch. in United States Mineral Resources, Professional Paper 820, 1973.
Platinum-Group Metals. Ch. in Mineral Commodity Summaries, annual.
Precious Metals. Mineral Industry Surveys, monthly.

Other

Chemical & Engineering News.
Fuel Cell Today (www.fuelcelltoday.com).
International Platinum Association.
Platinum Guild International.
Platinum-Group Metals. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.
Roskill Information Services Ltd.

TABLE 1
SALIENT PLATINUM-GROUP METALS STATISTICS[1]

(Kilograms metal content, unless otherwise specified)

		1998	1999	2000	2001	2002
United States:						
Mine production:						
Palladium[2]		10,600	9,800	10,300	12,100	14,800
Value	thousands	$98,500	$114,000	$228,000	$237,000	$162,000
Platinum[2]		3,240	2,920	3,110	3,610	4,390
Value	thousands	$39,000	$35,600	$54,900	$61,900	$76,500
Refinery production:						
Palladium		NA	10,400	7,980	9,790	5,700
Value	thousands	NA	$122,000	$178,000	$192,000	$62,200
Platinum		NA	12,900	15,800	15,000	15,200
Value	thousands	NA	$157,000	$278,000	$258,000	$265,000
Imports for consumption, refined:						
Iridium		1,950	2,250	2,700	3,110	2,100
Osmium		71	23	133	77	36
Palladium		176,000	189,000	181,000	160,000	117,000
Platinum, includes waste, scrap and coins		96,700	125,000	93,700	84,200	160,000
Rhodium		13,500	10,300	18,200	12,400	8,630
Ruthenium		8,880	11,400	20,900	8,170	9,890
Exports, refined:						
Iridium, osmium, and ruthenium (gross weight)		905	851	1,480	1,370	1,990
Palladium		36,700	43,800	57,900	36,800 r	42,700
Platinum		14,300	19,400	25,000	29,300	27,800
Rhodium		811	114	797	982	348
Stocks, National Defense Stockpile, December 31:						
Iridium		920	784	784	784	784
Palladium		38,800	28,200	19,000	16,300	5,870
Platinum		13,700	7,060	5,190	3,680	649
Price, average per troy ounce:						
Iridium[3]		$441.85	$411.40	$415.00	$415.25	$294.62
Palladium[4]		$289.76	$363.20	$691.84	$610.71	$339.68
Platinum[4]		$374.61	$378.94	$549.30	$533.29	$542.56
Rhodium[4]		$619.83	$904.35	$1,990.00	$1,600.00	$838.88
Ruthenium[3]		$47.95	$40.70	$129.76	$130.67	$66.33
Employment		620	954	1,290	1,620 r	1,580
World, mine production		354,000	374,000	378,000	408,000 r	423,000

rRevised. NA Not available.

[1]Data are rounded to no more than three significant digits, except prices.

[2]Source: Stillwater Mining Co., 2002 10-K report, p. 35.

[3]Price data are annual averages of daily Engelhard unfabricated quotations published in Platts Metals Week.

[4]Price data are annual Engelhard unfabricated quotations published in Platts Metals Week.

TABLE 2

U.S. IMPORTS FOR CONSUMPTION OF PLATINUM, BY COUNTRY[1]

(Kilograms metal content, unless otherwise specified)

Country	Platinum grain and nuggets		Platinum sponge		Other unwrought platinum		Platinum, other		Platinum waste and scrap		Platinum coins	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
2001	2,480	$40,200	68,700	$1,160,000	3,660	$62,200	5,330	$79,800	3,960	$89,900	53	$869
2002:												
Argentina	--	--	--	--	15	270	--	--	--	--	--	--
Australia	1	7	236	2,820	--	--	(2)	2	--	--	4	117
Belgium	--	--	5,500	89,500	167	2,240	--	--	--	--	--	--
Brazil	--	--	--	--	--	--	--	--	1,390	4,400	--	--
Canada	33	558	2	26	(2)	8	487	8,750	18,000	8,370	6	112
Chile	--	--	--	--	--	--	--	--	1,040	1,330	--	--
China	--	--	--	--	13	201	4	60	--	--	3	82
Colombia	--	--	--	--	389	5,890	2	23	1,510	673	--	--
France	--	--	62	1,270	--	--	28	645	63	1,510	--	--
Germany	285	5,180	2,610	45,900	592	9,370	2,260	33,000	22,800	15,900	(2)	5
Israel	--	--	--	--	787	11,700	--	--	--	--	--	--
Italy	--	--	368	6,220	62	1,180	132	2,350	--	--	--	--
Japan	--	--	16	274	439	5,500	286	4,990	435	5,100	--	--
Korea, Republic of	--	--	--	--	405	7,340	7	97	18,700	4,310	--	--
Malaysia	--	--	--	--	--	--	--	--	1,470	294	--	--
Mexico	--	--	33	516	(2)	6	--	--	682	588	--	--
Norway	--	--	511	8,530	5	98	--	--	--	--	--	--
Russia	6	129	3,140	55,100	32	602	1	14	--	--	--	--
South Africa	1,330	24,200	44,200	690,000	126	2,060	250	4,290	45	1,610	--	--
Switzerland	138	2,120	1,200	18,500	149	2,260	692	10,900	--	--	--	--
United Kingdom	117	1,780	14,700	248,000	288	4,790	765	13,300	11,000	16,400	6	101
Venezuela	--	--	--	--	15	137	24	208	--	--	--	--
Other	3	70	--	--	4	85	12	138	328	935	--	--
Total	1,910	34,000	72,600	1,170,000	3,490	53,700	4,950	78,700	77,500	61,400	20	417

-- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Less than 1/2 unit.

Source: U.S. Census Bureau.

TABLE 3

U.S. IMPORTS FOR CONSUMPTION OF PLATINUM-GROUP METALS, BY COUNTRY[1]

(Kilograms metal content, unless otherwise specified)

Country	Unwrought palladium		Palladium, other		Iridium[2]		Unwrought osmium		Unwrought ruthenium		Rhodium[3]	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
2001	146,000	$2,970,000	13,600	$257,000	3,110	$30,300	77	$646	8,170	$30,700	12,400	$594,000
2002:												
Belgium	9,900	93,700	2,390	13,300	--	--	--	--	--	--	1,040	29,600
Canada	2,100	18,900	5	94	--	--	--	--	--	--	--	--
Chile	--	--	50	378	--	--	--	--	--	--	--	--
China	1,740	18,500	10	101	--	--	6	46	--	--	4	89
Colombia	3	22	--	--	--	--	--	--	--	--	--	--
Ecuador	--	--	--	--	8	11	--	--	--	--	--	--
Finland	--	--	1	3	--	--	--	--	--	--	(4)	2
France	(4)	3	43	885	--	--	--	--	--	--	--	--
Germany	1,780	20,400	7,600	72,200	237	2,370	--	--	1,260	3,000	313	8,070
Guadeloupe	--	--	--	--	--	--	--	--	--	--	(4)	24
Honduras	7	20	--	--	--	--	--	--	--	--	--	--
Hong Kong	--	--	--	--	--	--	--	--	--	--	(4)	6
Italy	115	1,180	509	5,330	1	34	--	--	--	--	34	825
Japan	3,350	21,200	868	3,630	--	--	--	--	--	--	42	1,370
Korea, Republic of	51	191	--	--	--	--	--	--	--	--	53	1,340
Mexico	2	17	26	303	--	--	--	--	--	--	2	57
Norway	5,570	54,500	250	2,560	--	--	--	--	--	--	103	1,930
Philippines	(4)	4	--	--	--	--	--	--	--	--	--	--
Russia	28,900	319,000	3,750	32,400	--	--	--	--	--	--	1,810	102,000
Singapore	--	--	3	46	--	--	--	--	--	--	--	--
South Africa	24,900	262,000	3,930	33,300	803	7,330	30	248	8,240	17,500	4,820	132,000
Spain	5	49	--	--	--	--	--	--	--	--	--	--
Sweden	465	1,900	--	--	--	--	--	--	--	--	--	--
Switzerland	1,890	19,100	559	5,200	--	--	--	--	9	21	--	--
Taiwan	(4)	4	2	16	--	--	--	--	--	--	--	--
United Kingdom	13,800	138,000	1,960	19,600	1,050	10,300	--	--	377	839	417	10,400
Total	94,600	968,000	22,000	189,000	2,100	20,100	36	294	9,890	21,400	8,630	288,000

-- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Unwrought and other forms of iridium.

[3]Unwrought and other forms of rhodium.

[4]Less than 1/2 unit.

Source: U.S. Census Bureau.

TABLE 4
U.S. EXPORTS OF PLATINUM-GROUP METALS, BY COUNTRY[1]

(Kilograms metal content, unless otherwise specified)

Country	Palladium		Platinum		Platinum, waste and scrap		Iridium, osmium and ruthenium		Rhodium	
	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)	Quantity	Value (thousands)
2001	36,800 r	$489,000	29,300	$391,000	12,900	$322,000	1,370	$16,600	982	$59,900
2002:										
Argentina	--	--	4	78	--	--	--	--	1	131
Australia	258	1,560	1,310	22,200	--	--	7	49	--	--
Austria	11	27	17	115	--	--	(2)	9	--	--
Bahamas, The	--	--	2	5	--	--	--	--	--	--
Belgium	133	1,100	19	312	23	330	--	--	--	--
Bermuda	--	--	1	16	--	--	--	--	--	--
Brazil	61	396	342	5,060	--	--	1	24	--	--
Canada	3,350	37,600	2,550	32,600	2,240	19,800	14	105	-2	61
Chile	--	--	316	2,340	--	--	--	--	--	--
China	491	4,330	268	3,680	(2)	5	5	87	7	257
Colombia	12	61	1	16	(2)	8	--	--	(2)	5
Costa Rica	6	16	1	13	--	--	--	--	--	--
Cyprus	2	5	--	--	--	--	--	--	--	--
Denmark	71	280	20	77	--	--	--	--	--	--
Dominican Republic	6	33	2	6	--	--	--	--	(2)	5
El Salvador	2	3	--	--	--	--	--	--	--	--
Finland	27	180	15	92	--	--	--	--	--	--
France	364	1,870	292	2,430	--	--	12	34	9	490
Gambia, The	--	--	1	16	--	--	--	--	--	--
Germany	3,580	16,500	5,440	60,600	3,570	32,000	47	564	138	3,250
Haiti	8	29	--	--	--	--	--	--	--	--
Hong Kong	199	872	110	1,090	(2)	9	8	117	5	551
India	1	23	1	5	--	--	--	--	1	131
Ireland	502	1,850	302	3,830	--	--	758	14,000	1	134
Israel	80	573	12	148	(2)	4	1	15	(2)	3
Italy	73	282	105	1,650	1	12	--	--	(2)	4
Japan	2,940	22,700	5,930	75,600	1,030	18,500	60	577	141	3,920
Korea, Republic of	537	5,720	48	395	(2)	7	3	26	--	--
Liechtenstein	--	--	11	191	--	--	--	--	--	--
Malaysia	7	10	104	1,160	--	--	2	38	--	--
Mexico	205	514	97	828	1	14	9	104	1	169
Netherlands	527	3,020	108	513	2	16	3	57	--	--
New Zealand	100	493	35	163	--	--	--	--	--	--
Norway	42	208	23	155	3	24	2	7	--	--
Peru	--	--	2	10	3	117	--	--	--	--
Philippines	57	162	44	141	--	--	--	--	--	--
Poland	2	4	2	21	37	350	--	--	--	--
Singapore	904	1,390	34	195	--	--	6	67	3	515
Slovakia	39	126	--	--	--	--	--	--	--	--
Slovenia	52	170	--	--	--	--	--	--	--	--
South Africa	--	--	14	193	--	--	--	--	1	155
Spain	95	572	19	93	--	--	--	--	--	--
Sweden	10	38	23	255	--	--	1	7	--	--
Switzerland	20,400	216,000	4,700	49,200	1	5	1	4	--	--
Taiwan	3,810	12,200	426	1,850	10,800	175,000	5	106	1	101
Thailand	95	422	94	460	--	--	1	6	(2)	34
Trinidad and Tobago	2	6	--	--	--	--	--	--	--	--
Turkey	4	39	5	24	--	--	--	--	(2)	30
United Arab Emirates	3	22	--	--	--	--	--	--	(2)	25
United Kingdom	3,570	17,800	4,970	62,900	--	--	1,050	10,300	39	2,540
Other	22	63	29	146	--	--	1	3	1	21
Total	42,700	350,000	27,800	331,000	17,700	247,000	1,990	26,300	348	12,500

rRevised. -- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Less than 1/2 unit.

Source: U.S. Census Bureau.

TABLE 5
PLATINUM-GROUP METALS: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Kilograms)

Country[3]	1998	1999	2000	2001	2002[e]
Platinum:					
Australia[4]	150 e	90	171 r	174 r	200
Canada	5,640	5,663	6,302	7,410 r	7,400
Colombia	411	448	339	674 r	700
Finland	500 r	500 r	441 r	510 r	500
Japan[5]	533	737	782	550 e	500
Poland[6, 7]	20	21	21	20 e	20
Russia[e]	30,000	32,000	35,000	36,000 r	35,000
Serbia and Montenegro[e]	10	5	5	5	5
South Africa	116,483	121,304	114,459	130,307	133,796 [8]
United States[9]	3,240	2,920	3,110	3,610	4,390 [8]
Zimbabwe	2,730	479	505	519 r	1,500
Total	160,000 r	164,000	161,000	180,000 r	184,000
Palladium:					
Australia[4]	800 e	816	812 r	828 r	800
Canada	8,905	8,939	9,949	11,700 r	11,500
Finland[e]	150	150	-- r	-- r	--
Japan[5]	4,151	5,354	4,712	4,830	5,000
Poland[6, 7]	12	12	12	12 e	12
Russia[e]	70,000	75,000	84,000	85,000 r	84,000
Serbia and Montenegro[e]	50	25	25	25	25
South Africa	56,608	58,164	55,818	62,601	64,244 [8]
United States[9]	10,600	9,800	10,300	12,100	14,800 [8]
Zimbabwe	1,855	342	366	371 r	1,080 [8]
Total	153,000	159,000	166,000	177,000 r	181,000
Other platinum-group metals:					
Canada[e]	742	716	720	720	700
Russia[e]	13,500	13,700	14,100	14,500	14,500
South Africa	26,862	37,011	36,493	35,839 r	41,721 [8]
Zimbabwe	177	37	40	42 r	120
Total	41,300	51,500	51,400	51,100 r	57,000
Grand total	354,000	374,000	378,000	408,000 r	423,000

[e]Estimated. [r]Revised. -- Zero.

[1]World totals, U.S. data, and estimated data have been rounded to no more than three significant digits; may not add to totals shown.

[2]Table includes data available through April 29, 2003. Platinum-group metal (PGM) production by Germany, Norway, and the United Kingdom is not included in this table because the production is derived wholly from imported metallurgical products and to include it would result in double counting.

[3]In addition to the countries listed, China, Indonesia, and the Philippines are believed to produce PGM, and several other countries may also do so, but output is not reported quantitatively, and there is no reliable basis for the formulation of estimates of output levels. A part of this output not specifically reported by country is, however presumably included in this table credited to Japan.

[4]PGM recovered from nickel ore that is processed domestically. PGM in exported nickel ore are extracted in the importing countries, such as Japan, and are believed to be included in the production figures for those countries.

[5]Production derived entirely from imported ores.

[6]Based on official Polish estimates.

[7]Estimates based on reported platinum and palladium-bearing final (residual) slimes and then average Pt and Pd content from electrolytic copper refining.

[8]Reported figure.

[9]A very small quantity of byproduct platinum and palladium produced from gold-copper ores was excluded.